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One of the most startling developments in recent years is the penetrating of the electronic computer and mathematics into almost every phase of human activity.

If there is a library, then someone is at work representing (inside the memory of a computer) the book number, its title, its shelf location, who has it on loan, the date due, the author, its call number, its cross references, its frequency of use. . . . A library is like a population that does not bury its dead; nay its living too, for the publication explosion engulfs us. Hence out of this rather straightforward effort of getting some of the present information about a library into a more manipulatable form, will emerge the "information storage and retrieval system" of tomorrow in which the old physical book and printed paper page may well become a relic like an ancient scroll.

Wherever one finds a system for processing insurance premiums, or a system for keeping track of bank deposits and withdrawals, or an airline reservation system, or any other inventory control system, someone is at work simulating such a system in an electronic computer and forging the links whereby the real world supplies information to the computers and the orders of the computer are translated into real actions.

It is correct to regard much of what has been done so far as a vast tooling up, a preparation for new ways to do old tasks. It is the exponential improvement in electronic hardware, the availability of new machine languages and special machine programs that now permit the practical implementation of these ideas. We are now witnessing an accelerated trend towards automation of simple human control tasks.

Operations Research refers to the science of decision and its application. In its broad sense, the word "cybernetics", the science of control, may be used in its place. This science is directed towards those tasks that humans have not yet delegated to machines. Tasks involving human energy and (as we have seen) those involving simple human control have already been conceded to machines even though they have not been fully taken over by them. It is the automation of higher order human decision processes that is the last citadel.

At the lowest level of these higher order tasks is the human ability to recognize patterns in sight, sound, touch, smell, and taste. Although these tasks may elicite simple responses (as, turn the wheel to the right or left), nevertheless human presence is needed because a complex mental recognition process is involved. It would be easy to get a machine to mechanically separate returned Coke and Pepsi bottles if it were smart enough to recognize which is which.

At the next level of complexity is the human ability to observe and to adapt to physical movement; for example, to observe a dial or a car's angle to the road direction, and to manipulate certain con-

trols to change the physical movement in some preferred way. Here again it is easy to get a machine to make the physical movement of the controls if it were only smart enough to adapt to trends in the observed movements as changes are made in the controls.

Although pattern recognition is by no means a solved problem, banks do have machines that recognize account numbers on checks and machines do exist that give change for a dollar bill and not for a blank piece of paper. Automatic feed-back controls in simple situations have been known for a long time. The governor invented by Watt to control the speed of a steam engine is such a device. Closed loop controls using computers to analyse input data are now a reality in certain large-scale operations such as oil refineries, chemical plants, and power distribution systems.

At still a higher level of complexity are those decision processes that involve many alternative courses of action. An industrial complex may have at its disposal many types of equipment and a variety of raw materials and personnel skills. The complex could manufacture a vast variety of final products using many alternative process sequences. If the wrong decisions are made in the scheduling of the various processes, labor and machines are idle, throughput is reduced and in-process inventories are increased. If the wrong decisions are made in raw material selection, or the procedure for manufacture, or the choice of final product, labor and machines are overworked, expensive materials are purchased when cheap ones will do, and unwanted products are dumped on the market.

To circumvent these difficulties, large companies and government enterprises have developed staff planning groups. In military planning it was once possible for a supreme commander to personally plan operations. As the planning problem expanded in space, time, and general complexity, he surrounded himself with a general staff of specialists. These planning staffs permit the subdivision of the planning process by assigning experts to handle each part; they try to gather data in an orderly way, to draw up over-all plans, and to consider a few of the possible alternatives. To draw up an over-all plan of an airforce during World War II took many months. In some Western countries national planning is now done. In communistic countries this bureaucratic process is more formal and extensive. The European Common Market represents staff planning at an international level.

In the last two decades great strides have been made to effectively use the electronic computers as part of the planning process. The most historic of all such efforts was Project SCOOP (Scientific Computation of Optimal Programs) initiated by the Air Force around 1947. Part of the ramifications of this project included a 400 sector interindustry model of the national economy. Except for the preparation of input data, the calculation of various planning programs was completely mechanized. Their sizes were truly enormous. The program typically stated by months (for 36 months) the level of each type activity for thousands of activity types. The balanced flows of some tens of thousands of input and output items (necessary to sup-

port these activities) were also stated as a function of time. As ground rules, appropriations, or international conditions changed, these programs were recalculated rapidly again and again.

This early pioneering effort at mechanization of the planning process showed that it was possible to describe in mathematical terms the interdependence of various activities, be it training activities, a combat unit, an engine over-haul activity, or the steps in an industrial process or the shipment of goods from various origins to numerous destinations. The trick is to make each activity elementary enough so that its inputs and outputs are proportional to the level of the activity. The resulting mathematical system is a system of linear inequalities called a linear program. By incorporating this mathematical approach, planning staffs are relieved of much of the drudgery and can concentrate on over-all objectives.

True optimization is the revolutionary contribution of modern research to decision processes. In the entire history of mankind a great gulf has always existed between man's aspirations and his actions. He may have wished to state his wants in terms of objectives but there were so many possible different ways to go about it, each with its own good and bad, that it was impossible to compare them and to say which was the best. Man invariably turned to a leader, a manager, a governor, or a commanding officer whose "experience" and "mature judgement" would point the way. Inevitably, "the way" became the new objective. This substitution of the means for the objective is the history of mankind. The slogan "the end justifies

the means" perhaps could be better stated as "the end might conceivably justify the means if one could ever remember what the original objective was."

Because man did not have the ability to select the best among many infinities of alternatives, his planning was characterized by many ground rules and policies dictated by men with "mature judgement". It seemed therefore impossible that planning could ever be done by computer without constantly stopping the machine to await decisions from the experts. The habits of centuries are not easily overcome but planning staffs, freed from the drudgery of computing out one or possibly two alternatives, are now beginning to express themselves in terms of over-all objectives and to ask the computers to find them the "best".

Computation of truly optimum programs was beyond the capabilities of SCOOP. This aspect found a better application in the less complex problems of industry. As the power of computing machinery grew and as the power of methods proposed by mathematicians grew, optimal solutions of large scale complex planning problems have become a reality. The petroleum industry is a leader in the diversification, scope, and sophistication of its use of advanced planning methods, such as linear and nonlinear programming.

These mathematical systems are truly among the largest in the world. Typical problems run from 300 to 800 equations depending on the company. In Europe the new code "Ophelia" is designed to solve practical problems of up to 4000 equations. In all cases the

number of possible activities (variables) run in the thousands. Paper companies, chemical companies, airlines, natural gas distributors, steel companies are at various stages of sophistication in their use of these advanced planning methods. One large food processor has successfully tested out a new method called the Decomposition Principle for solving extremely large systems. A problem involving 30,000 equations and over a million variables has been optimized.

Let us now turn to cybernetics developments in U.S.S.R. In 1939 Leonid Kantorovich proposed that mathematical methods be applied to planning problems. For one and a half decades his work was unknown to the Western world as well as in Russia for communist policy had shelved it as dangerous. However, by 1959, two decades later, the Soviet policy had completely reversed. The Supreme Soviet decreed cybernetics top priority.

Scientific circles in Russia, as a result, began a vast tooling up. Computers are not as plentiful as in U.S.A. but this does not prevent education on their design, nor work on the development of machine languages, nor work on the design of complex control systems. It is stated by one authority that there are <u>ten times</u> as many engineers and mathematicians working on control theory in U.S.S.R. than in U.S.A.

It is reported that Russians feel that through their efforts in cybernetics they will outdistance the productivity of the Western World. According to economists who have studied developments

there, the Soviets feel that the weak point of their planning system lies at the middle management level, the factory managers. This group apparently is unable to exercise initiative and modify their given production plans. On the other hand their top management (at industrial and governmental levels) appear to be the equal of ours. The same is true at their lower management levels. Their hope is to replace their middle management planning with a highly flexible scheme which they believe is inherently superior to ours. We should not dismiss their idea too quickly. It should be noted that, historically, it has been difficult to change the direction of large-scale enterprises once they have gathered momentum. These momentums have been the underlying cause of our business cycles and depressions. It would thus appear that timely, balanced, optimal programs encompassing a broad spectrum of enterprises could have enormous payoff. They believe that excellent detailed planning and rapid flow of information in both directions could avoid these problems completely. Soviet Academician Vasili Nemchinov sums it up this way:

> "The communist system alone gives sufficient room to apply the combination of mathematics and cybernetics to the national economy. Only under the system of public ownership is it possible to introduce into the economy a single automated electronic system of planning. In a private enterprise system the use of cybernetics is restricted by the framework of companies, corporations and syndicates."

Whether computers and programming can accomplish this miracle of putting the Soviet ahead of everyone else is therefore the key issue. We have already seen that every step necessary to fulfill

this aim has already been service tested on a large scale in this country. Project SCOOP by 1952 had shown that it was possible to mechanize government (military) planning. We have seen the rapid improvements in computer technology since that date. We have seen how computers are penetrating into record keeping and into process control so that input data could be made instantly available to the planning system and the results of the computation could be prepared in a form for necessary feed-back action. Can computers be programmed to solve the truly immense systems characteristic of a national economy, particularly dynamic systems involving optimization? Here again we note that by use of the decomposition principle of linear programs, systems of the order of 30,000 equations and 10^6 variables have already been solved. Ponder the statement made by the Russian, Malkov: "Half of the mathematicians in the Moscow Computing Center are working on decomposition problems." Even if total system optimization is presently impossible, <u>and it is</u>, there are all kinds of schemes involving partial aggregation that permit near-optimal solutions.

Nothing in this country matches the sense of urgency nor the priority that the Russians have placed on cybernetics, particularly the emphasis they place on those aspects which we usually refer to as operations research.

We are witnessing a computer revolution in which nearly all tasks of man--be it manual labor or simple control, pattern recog-

nition or complex higher order decision making--all are being reduced to mathematical terms and their solution delegated to computers. Are our government, our industry, our research centers and most important, our universities, moving rapidly enough to prepare us for this new world?